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Large strip RPCs for the LEPS2 TOF system

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Abstract

High time-resolution resistive plate chambers (RPCs) with large-size readout strips are developed for the time-of-flight (TOF) detector system of the LEPS2 experiment at SPring-8. The experimental requirement is a 50-ps time resolution for a strip size larger than 100 cm^2/channel. We are able to achieve 50-ps time resolutions with 2.5 × 100 cm^2 strips by directly connecting the amplifiers to strips. With the same time resolution, the number of front-end electronics (FEE) is also reduced by signal addition.

Keywords: RPC, Time-of-Flight, PID, Time resolution, Strip, Large area

1. Introduction

Resistive Plate Chambers (RPCs) are fascinating gaseous counters in terms of their superb intrinsic time resolutions and relative cheap cost. The gas gaps of RPCs are formed with high resistivity glasses to be a few hundred micrometers. When charged particles pass, avalanches occur in the gas gaps and electric signals are induced on readout strips. The small gaps produce small time fluctuations of avalanches. Because of the short drifting distance in the small gap, the time fluctuation of avalanche is limited. The intrinsic time resolution of RPC could be further reduced to be 20 ps level by increasing the number of gaps. However, the sharp leading edge of the induced signal is distorted during its propagation on readout strips and this results in the deterioration of time resolutions. Single-ended pads for the readout strips have been adopted in the early TOF-RPCs e.g. ALICE-TOF and STAR-TOF [1, 2]. Small single-end pads are superior in terms of small distortion of signals. However, since signal propagation velocity is about 50 ps/cm, the variation of the hit position largely affects the time resolution even the pad size is less than 10 cm^2. For example, the time resolution of ALICE-RPCs is 50 ps when the beam spot is 1 × 1 cm^2 [3] while it becomes 86 ps with full pad (2.4 × 3.7 cm^2) [4]. Nowadays, strip-type readout which signals are read from both ends is becoming popular for TOF-RPCs. The degradation of the time resolution due to the ambiguity of the position can in principle be overcome by averaging the measurement from both ends. However, it is critical to carefully match the impedance between the strip and the readout electronic in this approach; otherwise the signals are reflected and distorted at the connection points of strips and readout electronics. As an example, the strip geometry of FOPI-RPCs was made as 0.2 × 90 cm^2 such that the impedance of strip matches with the readout electronics [5]. Thus, the TOF-RPCs with the time resolution better than 100 ps is generally of the strip size less than 10 cm^2. However, the usage of small-size strips requires the huge number of readout electronics for large acceptance. This paper presents the development of RPCs which have strips of 250 cm^2. The RPCs are developed for the LEPS2 experiment at SPring-8, Japan. The front-end electronics composed of amplifiers, discriminators and stretchers are built with commercial chips. As to be described in the following sections, a good time resolution of 50 ps is achieved by directly connecting the amplifiers to the strips and by choosing proper width and interval of the strips. We also adopt a signal addition technique so that the number of readout electronics is reduced by half.

2. The LEPS2 experiment

The Laser-Electron Photon experiments at SPring-8 (LEPS) has been studying hadron physics via photo-productions since 2000. SPring-8 circulates 8-GeV electrons in the storage ring. At the LEPS beamline, UV-lasers with energies of 3.5 - 4.7 eV are injected to the storage ring. The laser photons then scatter with the 8-GeV electrons and a high energy photon beam up to 3 GeV is produced. The high energy photon beam is transported to the LEPS experimental hatch and is irradiated to the target. The charged particles produced from the hadronic reactions are measured in the LEPS spectrometer. The acceptance of the spectrometer is limited to the forward angle less than 25 degrees.

In 2011, the construction of a new LEPS2 beamline started. A new experimental building has been built and a new large 4π spectrometer is under construction. The acceptance of charged particles in the LEPS2 experiment is much larger than that of the LEPS spectrometer. In addition, the beam intensity of the LEPS2 beamline is increased by one order of magnitude from the one of the LEPS to be 10^7 cps.

Fig. 1 shows the schematic drawing of the LEPS2 spectrometer. The solenoid magnet is the one used previously in the

AGS-E949 experiment at the Brookhaven National Laboratory (BNL). The tracking functionality is performed by three types of detectors; a Silicon Strip Detector (SSD), a Time Projection Chamber (TPC) and four Drift Chambers (DC). The energy of emitting photons is measured by Electromagnetic calorimeters (EMCAL). The particle identification (PID) is performed by the measurement in three detectors; Time-of-Propagation counters (TOP) [6], Aerogel Cherenkov counters (AC) and RPCs.

RPCs are mainly used to distinguish kaons from pions with momenta up to 1.1 GeV/c via the Time-of-Flight (TOF) measurement. RPCs cover a barrel region of a radius of 0.9 m and a length of 2 m. The total coverage area is 10 m^2. Because of the short flight length, a very high time resolution, σ=50 ps, is required in order to achieve the separation of 1.1 GeV/c K/π in 3σ accuracy. In addition, an efficiency better than 99 % is also required because RPCs are used for the trigger decision. The particle rate at the barrel region is less than 1 Hz/cm^2 thus, high rate capability is not required. In order to save the cost for the electronics, the number of readout channels is required to be less than 1000. This means that the coverage per channel has to be larger than 100 cm^2. It is non-trivial to achieve a 50-ps time resolution for such a large strip. We developed several prototype RPCs with large readout strips and performed beam test. The prototype of the front end electronics (FEE) were developed and aimed to minimize the effect of signal distortion. A signal addition technique was applied and tested to reduce the number of channels.

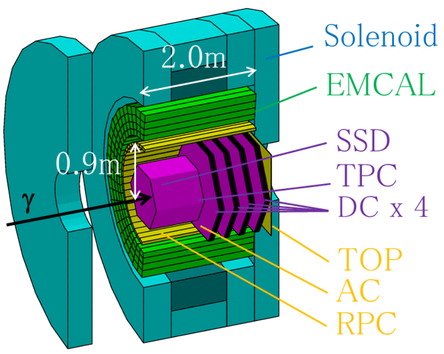

Figure 1: The LEPS2 spectrometer with the solenoid magnet moved from BNL. A SSD, a TPC and four DCs are used for the charged-particle tracking. The energy of photons is measured by EMCAL. The PID is done by TOPs, ACs and RPCs.

3. Description of the prototype RPCs

We constructed several prototype RPCs with different strip size and interval between the strips. A schematic drawing of the RPC is shown in Fig. 2. A five-gap and double-stack configuration and strip-type readout was used based on our previous studies [7]. The gap width and the glass thickness were 260 μm and 400 μm, respectively. High voltages are applied on the carbon tapes attached to the outer glasses. For the test of different width of readout strips, 110 cm × 15 cm glasses were used and the strip length was fixed to be 108 cm. For other tests, the glass size was 102 cm × 23 cm and the strip length was 100 cm. The gas was mixture of 90% $C_2H_2F_4$ (R134a), 5% SF_6 and 5% C_4H_{10} (butane). The time resolution and the efficiency were evaluated using RPCs with various configurations of strip width and strip interval. Details are described in Section 6. The anode strips are connected to the readout of FEEs and the cathode strips are grounded.

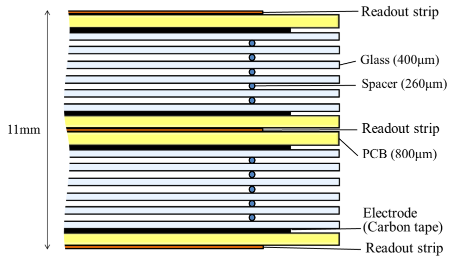

Figure 2: The schematic drawing of a prototype RPC. A five-gap and double-stack configuration was chosen. The thickness of the glass, the spacer and the PCB was 260 μm, 400 μm and 800 μm, respectively. High voltages are applied on the carbon tapes. Signals of anode strips are read out by FEEs.

4. Specifications of the FEEs

Three components were developed for the FEEs: amplifiers, discriminators and stretchers. The schematic drawing of the FEE system is shown in Fig. 3. The amplifiers have two different outputs for the individual measurement of ADC and TDC of the hit. The signal from the strip is amplified by two cascaded RFMD RF3376 chips, which have a 3 dB bandwidth at 2 GHz. The gain of cascaded RF3376 is about 200 and the rising and falling time is about 0.5 ns at 500 MHz. The amplified signal is split into two lines. One is connected to the discriminator board for the measurement of TDC. The other is connected to the Analog Device AD8014 chip and used for ADC. Most notably, the signals of two neighboring strips can be added up at the input of AD8014. This scheme reduces the number of ADC modules and delay cables by half. The ADCMP573BCPZ comparators are used for the discriminators. The chips have 8 GHz equivalent bandwidth. The threshold level was variable and set to -30 mV. The output pulse is PECL. Because the discriminator implements only comparators, the width of the input and output of the discriminators remains the same. Since the width of the output signals from the amplifier is too narrow (~2 ns) to be read by the TDC module, a stretcher which extends the width to be 10 ns is required. In addition, "OR" circuits are mounted on the stretcher board. The OR of two signals from different chambers are output from the stretcher. This design leads to a reduction of the number of channels of TDC modules by half. We verify that the time resolution does not degrade by the addition of signals at the amplifier (ADC) and the stretcher (TDC) in Section 6.4.

5. Experimental setup

We performed the beam test of prototype RPCs at the LEPS beamline. A schematic drawing of the experimental setup for

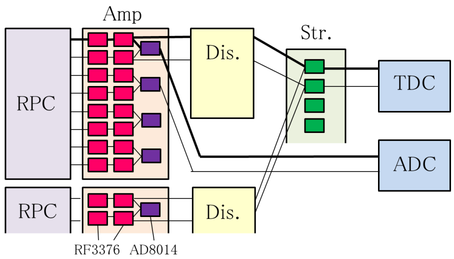

Figure 3: The schematic drawing of the FEE system.

the test is shown in Fig. 4. High energy photon beam was irradiated to a lead converter and electron-positron pairs are produced via pair-creations. The electrons with energy around 1.5 GeV/c are bent by a dipole magnet and irradiated to the RPCs. The applied high voltage of RPCs was 14 kV. The triggered region was defined to be 1×2 cm^2 by four finger scintillators located upstream and downstream of the RPCs. The hit rate was about 5 Hz/cm^2. The electrons in the SPring-8 storage ring has a bunch structure with a time spread of less than σ_e=15 ps and with an interval of 1966 ps. The start timing of TOF is defined by the RF signals from the accelerator which are synchronized with electron bunches. The time resolution of the RF signal is σ_{RF} ~4 ps. Since the custom FEEs have not been developed, a NIM amplifier, KN2104 manufactured by Kaizu Works was used for the test of the strip width and interval dependence of the time resolution. KN2104 is a voltage amplifier and its gain is about 5. The rising and falling time is about 2 ns at 500 MHz. The output was cascaded 2 times for the ADC measurements and 3 times for the TDC measurements. The input impedance of KN2104 is 50 Ω and the strips and the amplifier were connected via BNC connectors. The CAMAC system was used for the data acquisition system. The timing was measured by a GNC-040 TDC of DNomes Design and the charge was measured by a Repic RPC-022 ADC. The typical charge and time distribution before and after time-walk correction is shown in fig 5. The time resolution was derived by averaging the timing of both-ends after the time-walk correction. The time resolution of the GNC-040 TDC was σ_{TDC} ~18 ps. The intrinsic time resolution of the 10 gap RPC σ_{int} is ~ 25 ps [1]. The remaining uncertainty of the timing measurement comes from the signal distortion during its propagation on readout strip (σ_{prop}) and the FEE (σ_{FEE}). In order to achieve a TOF time resolution of 50 ps, the time jitter of the signal distortion and the FEE is required to be less than 40 ps.

6. Results

In this section, the results of beam test are shown. All configurations described in this section had the firing efficiency better than 99 %. Thus, only the time resolution is discussed in this section. The time resolutions shown below include all the effects on TOF measurement, i.e. $\sigma = \sqrt{\sigma_e^2 + \sigma_{RF}^2 + \sigma_{TDC}^2 + \sigma_{int}^2 + \sigma_{prop}^2 + \sigma_{FEE}^2}$.

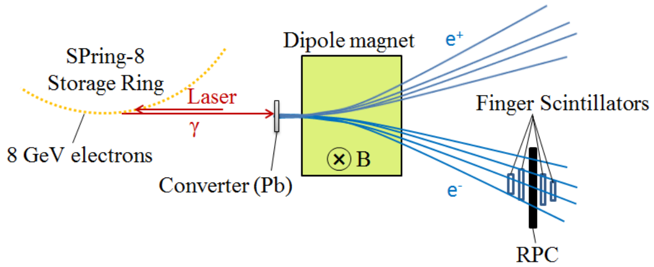

Figure 4: The experimental setup of the beam test. The beam test was performed at the LEPS beamline. High energy gamma rays hit a Pb converter. The electrons from the converter were bent by the dipole magnet and irradiated to RPCs. The triggered area was defined by four finger scintillators to be 1×2 cm^2.

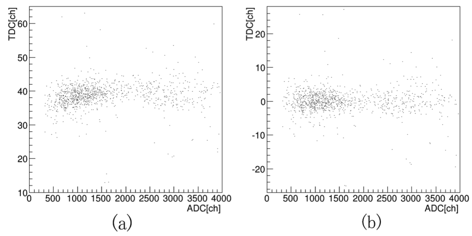

Figure 5: Typical charge and time distributions (a) before and (b) after the time-walk correction. A 2.5×100 cm^2 strip and the prototype FEEs are used.

6.1. Strip width optimization

In order to study the strip-width dependence of the time resolution, two types of RPCs with the strips of 2.5×108 cm^2 and 5.0×108 cm^2 were tested. These two configurations correspond to the number of readout channels of 800 and 400 needed for covering the barrel of the LEPS2 spectrometer, respectively. The KN2104 amplifier was used for this test.

Fig. 6 (a) and (b) show the typical signal from the RPCs with a 2.5 cm and a 5.0 cm wide strip. Due to impedance mismatches between the strip and the BNC connector, reflections are observed. The distortion of the 5.0 cm strip is worse than that of the 2.5 cm one. The time resolutions at several positions are shown in Fig. 7. The time resolution for the 2.5 cm strip was around 60 ps but worse resolution was observed at the position of -30 cm from the center in terms of position dependence. This is likely due to the impedance mismatch between strips and BNC feed-through. At the position of -30 cm from the center, the direct signal overlapped with the reflected signal and the leading edge was distorted [7]. The time resolution of the 5.0 cm strip was worse than that of the 2.5 cm one. Therefore, we confirmed that the 2.5 cm strip is the one with better time resolution.

6.2. Strip interval optimization

We tested three configurations (type A, B and C) for the optimization of the strip interval. The geometries are shown in Fig. 8. The width and the length of the strip was 25 mm and 100 cm, respectively. The strip interval of the type A was 2 mm, the type B was 0.5 mm and the type C was 1 mm. The middle strips of

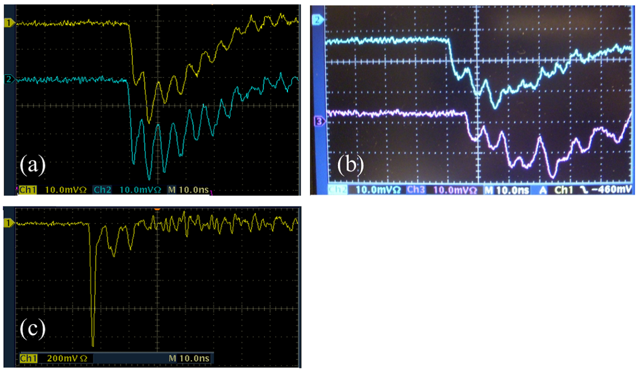

Figure 6: Typical signals of RPCs. (a) a 2.5 × 108 cm^2 strip with the KN2104 amplifier. (b) a 5.0 × 108 cm^2 strip with the KN2104 amplifier. (c) a 2.5 × 100 cm^2 strip with the prototype amplifier.

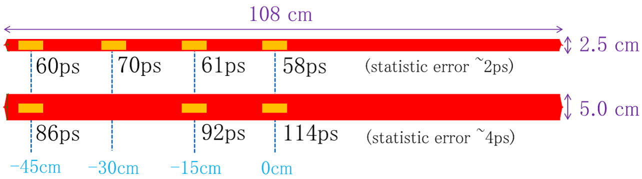

Figure 7: The time resolutions of the 2.5 × 108 cm^2 and the 5.0 × 108 cm^2 strips with the KN2104 amplifier. The time resolution of the 2.5 cm strip was 60~70 ps and that of the 5.0 cm strip was 85~115 ps.

type A and type B were used as the anode. The anodes of type C were the outer strips and the signals from the top and the bottom strips were combined at the input of the readout of the FEE. The outer strips of type C were shifted by 1 mm each other so that particles hit one of outer strips. The KN2104 amplifier was used for type A and type B, and the prototype amplifier was used for type C. The time resolution of measured position on the strip (Fig. 9(a)) was compared with that between strips (Fig. 9(b)) . The results are summarized in Table 1. The gas circulating term was not long enough during these measurements and this made the time resolution on the strip worse. No significant position dependence of the time resolution was observed for type B and C. Nevertheless, a worse resolution, 110 ps, was observed for type A.

Table 1: The time resolutions of configurations with different strip intervals. No position dependence of the time resolution was observed for type B and C. A worse resolution was observed for type A.

	type A	type B	type C
amplifier	KN2104	KN2104	prototype
on strip	77 ps ± 2 ps	76 ± 3 ps	61 ± 2 ps
between strip	110 ps ± 4 ps	75 ± 3 ps	60 ± 2 ps

6.3. Performance of the prototype FEEs

To minimize the effect of signal distortion, the prototype amplifiers were installed inside the gas container and directly connected to the readout strips as shown in Fig. 10. Fig. 6 (c) shows a typical signal from the prototype amplifiers and a 2.5 × 100 cm^2 strip. The reflection due to impedance mismatch was drastically reduced. This increases the S/N ratio of leading edges of signals. Fig. 11 shows the time resolution of the 2.5 × 100 cm^2 strip with the prototype FEE. The strip interval was 0.5 mm. The time resolution was measured at several triggered positions including ones between strips. This test was performed without signal addition. Time resolutions of 50 ps were achieved for all measured positions and there was no significant position dependence.

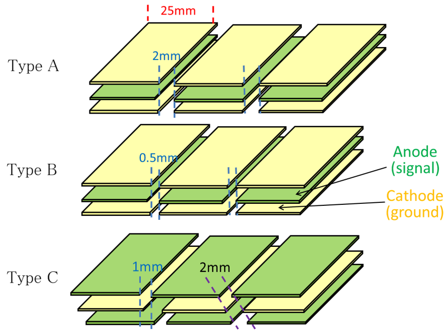

Figure 8: The different geometries of the strip interval. The strip interval was type A : 2 mm, type B : 0.5 mm and type C : 1 mm. The top and bottom strips of type C were shifted by 1 mm each other.

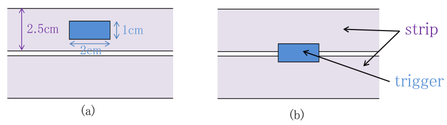

Figure 9: The trigger positions (a) on the strip (b) between strips.

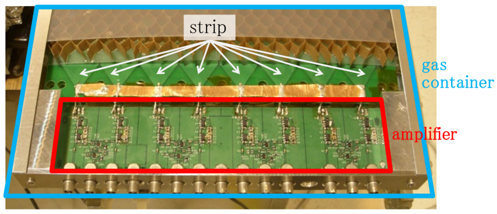

Figure 10: A photo of the prototype amplifier connected to the strips. The amplifier is installed inside the gas chamber.

6.4. Signal addition

The time resolution of added signals was also measured for a 2.5 × 100 cm^2 strip. This test was done with the readout from only one side of the strip since the amplifier of the other side failed to operate during the beam test. The time resolution of single-end readout was 62 ± 2 ps and 58 ± 2 ps without and with adding signals. The time resolution was not deteriorated by adding the signals of two strips. The time resolution of both-end readout is also expected not to be affected by adding signal.

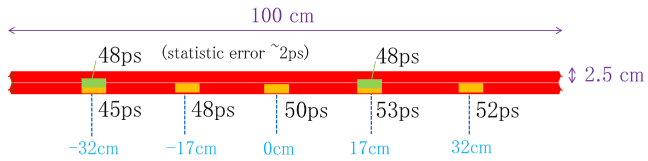

Figure 11: The time resolution of the 2.5×100 cm^2 strip by the prototype FEE. 50-ps time resolutions are achieved at all measured positions.

Thus, we can adopt the signal addition technique and can reduce the number of readout channels to be 400 in the LEPS2 experiment using 2.5×100 cm^2 strips.

7. Summary

We developed prototype RPCs and FEEs for the TOF system of the LEPS2 experiment at SPring-8. The aim is to achieve a TOF time resolution of 50 ps for readout strips larger than 100 cm^2/ch, which corresponds to 1000 channels of readout at the LEPS2. Optimization of the strip geometry was done by beam test and a 2.5×100 cm^2 strip with 0.5 mm interval was chosen. By directly connecting the prototype amplifiers to strips, a time resolution of 50 ps was achieved. Furthermore, the number of readout channels was reduced without sacrificing the time resolution by adding out the signals properly at FEEs. Finally, we demonstrated that a 50 ps time resolution was achievable by a configuration of strips and FEEs covering 250 cm^2/ch, corresponding to 400 readout channels at the LEPS2 experiment.

Acknowledgments

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